Terminal Area Fuel Burn Analyses for Environmental Models

Federal Aviation Administration

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By: David Senzig – Volpe Center

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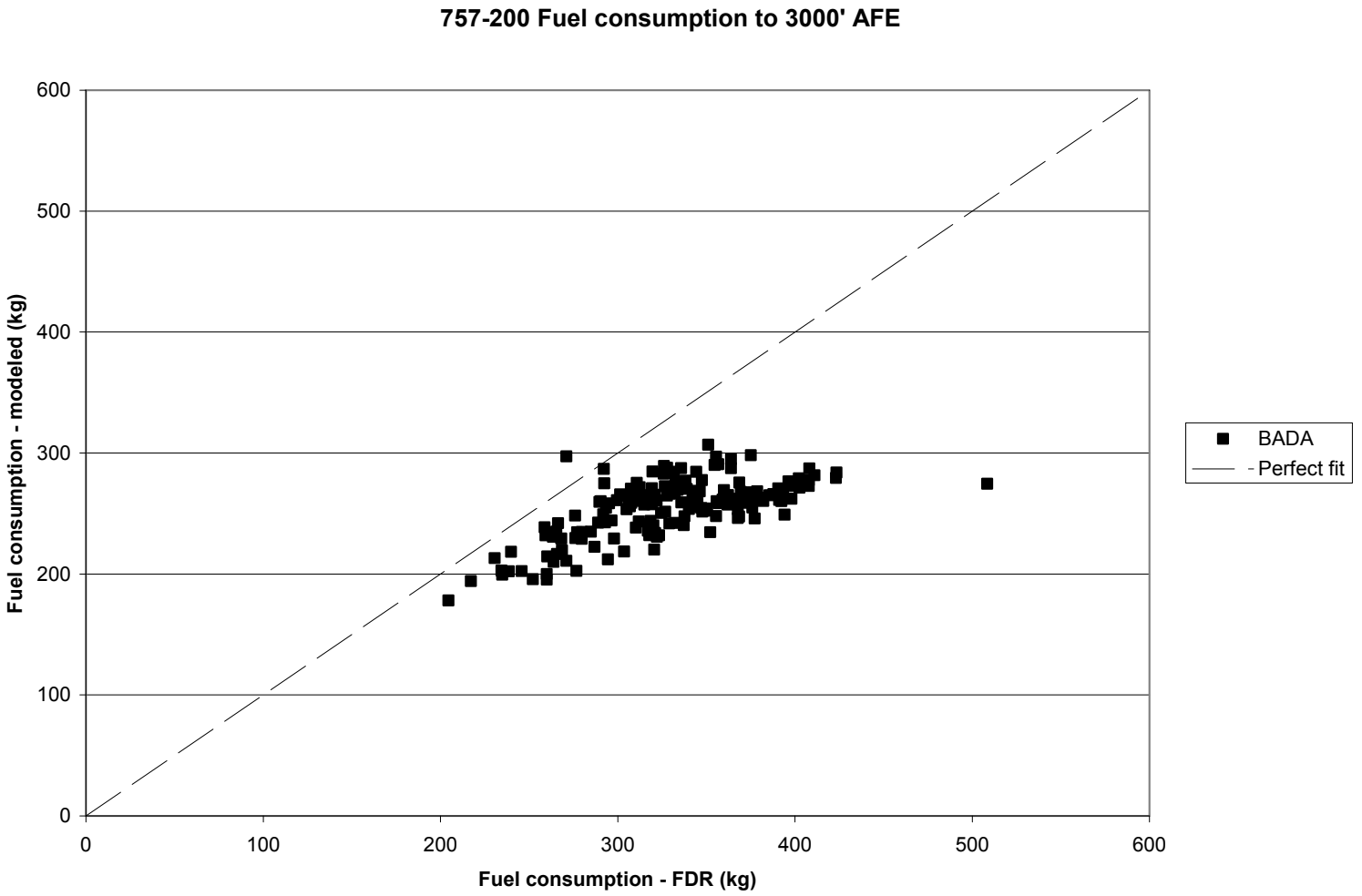
Status of FAA fuel burn modeling

- Historically, we have use a combination of SAE1845 thrust and EUROCONTROL's Base of Aircraft Data (BADA) Thrust Specific Fuel Consumption (TSFC) to predict fuel burn
- BADA is intended as an Air Traffic Management tool
- Flight Data Recorder (FDR) analyses showed that this method did not well model terminal area fuel burn for some aircraft
- Incorrect fuel burns potentially leads to incorrect emissions calculations and decisions based on erroneous data
- Other tools (such as APMT) will also be affected by the accuracy of these models

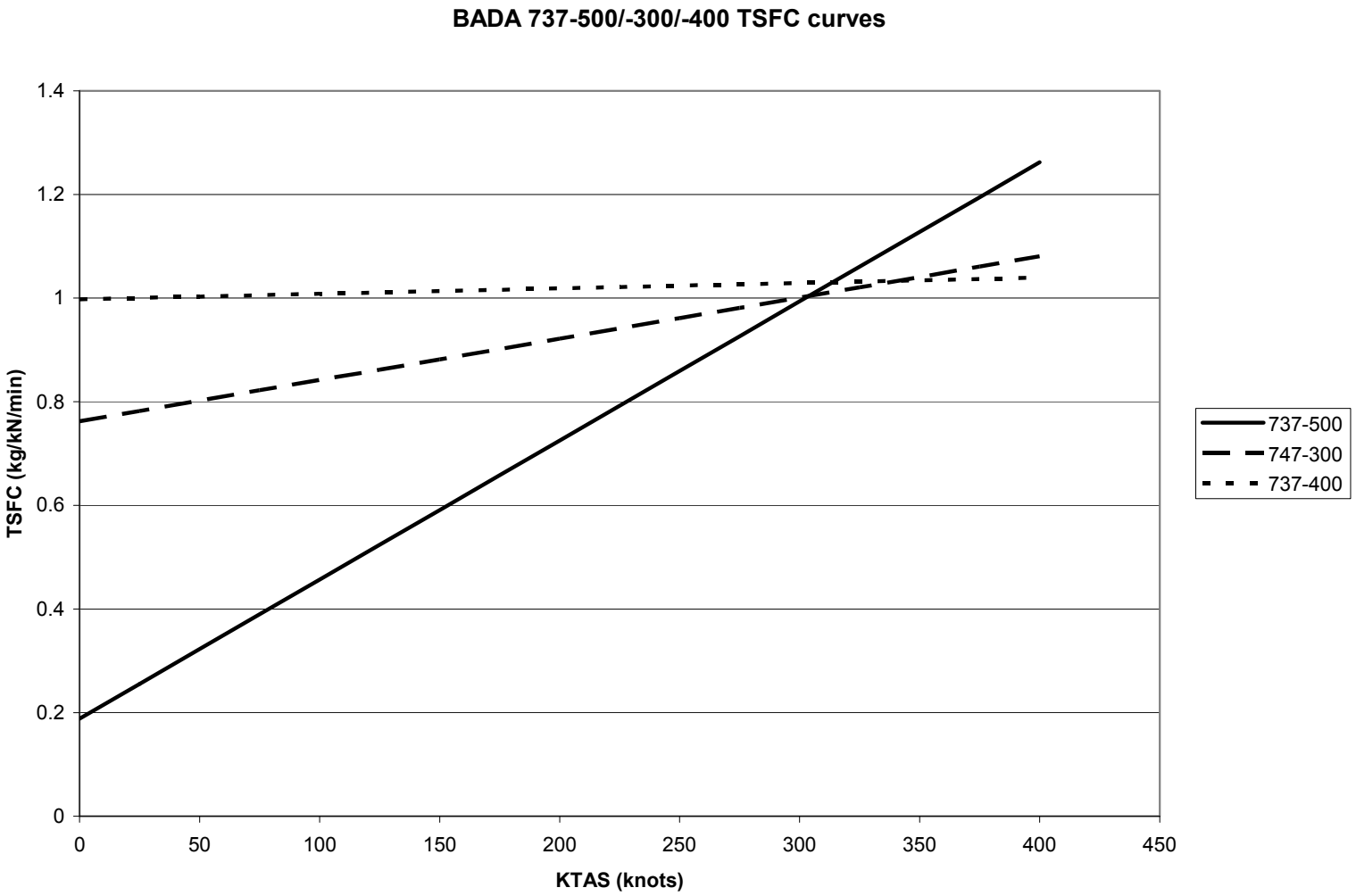
BADA under-prediction of fuel burn



Why the differences with FDR?

- BADA TSFC values are not intended to be used in the terminal area
  - Some aircraft have BADA TSFC coefficients that don't extrapolate well to the speeds used in the terminal area
  - These extrapolations issues appear uncorrelated to airframe or engine type

BADA TSFC variation

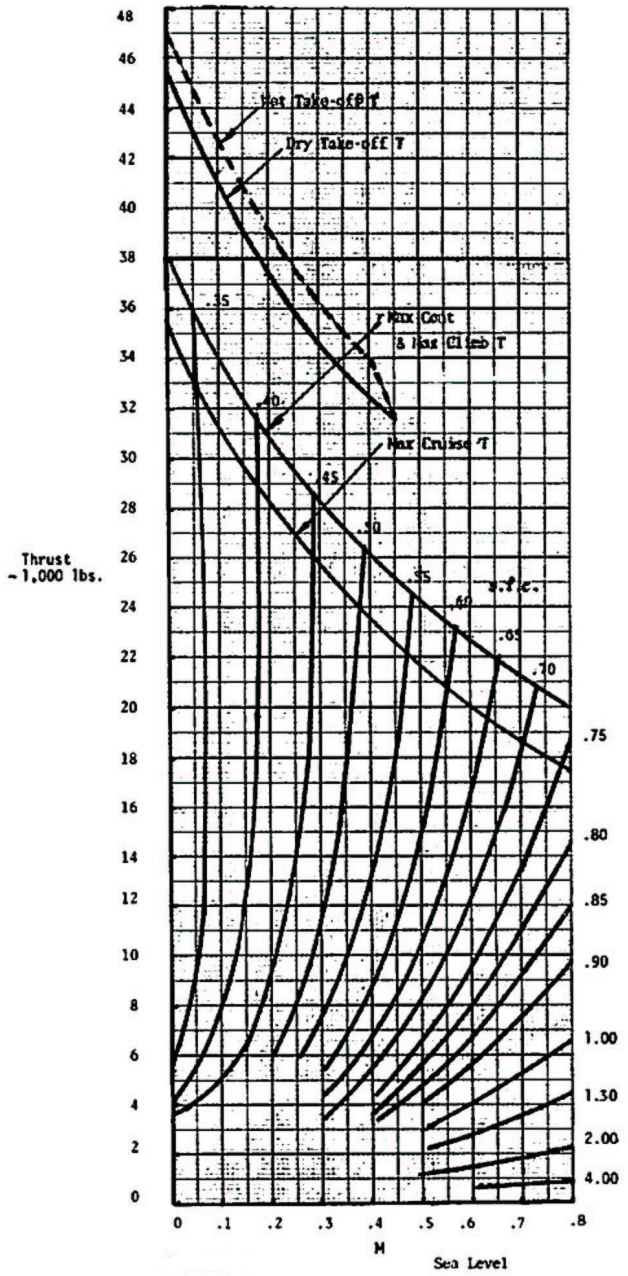


A proposed improvement

- Boeing and the FAA recently exchanged software tools – the Boeing Climb-Out Program (BCOP) and the FAA's Integrated Noise Model (INM).
  - FAA provided Boeing an executable version of the INM for inclusion in the next version of BCOP and in next generation performance tools
  - Boeing provided the FAA a copy of BCOP
- BCOP contains terminal area fuel burn data, for both departure and arrival

TSFC as a function of Mach and Thrust

- Example at Sea Level
  - Independent axis is Mach
  - Ordinate is Thrust
  - Curves are TSFC



The proposed fuel burn models

Departure:

$$TSFC/\sqrt{\theta} = k_1 + k_2 M + k_3 h_{MSL} + k_4 F/\delta$$

Arrival:

$$TSFC/\sqrt{\theta} = \alpha + \beta_1 M + \beta_2 e^{-\beta_3 \left(\frac{F}{\delta} \Big/ F_0 \right)}$$

The AEDT fuel burn model process

- Run BCOP with the closest match possible between the FDR aircraft and the AEDT aircraft
  - These BCOP runs are ICAO B procedures at S.L., 4K, and 6K up to 10,000 AFE.
  - The outputs are post-processed to collect the important performance parameters into a single text file

The AEDT fuel burn model process (cont.)

- Run statistical program on post-processed BCOP data to determine the coefficients for the model
- Add these coefficients to the AEDT database
- Quality test by comparing the results of the model to the FDR data.
  - Aircraft weight
  - Airport elevation and temperature
  - AEDT departure procedure based on weight

The AEDT fuel burn model process (cont.)

- Departures are modeled as AEDT (SAE-1845) procedure steps using the thrust calculated internally – we use the AEDT thrust applied to the modeled TSFC to calculate fuel flow

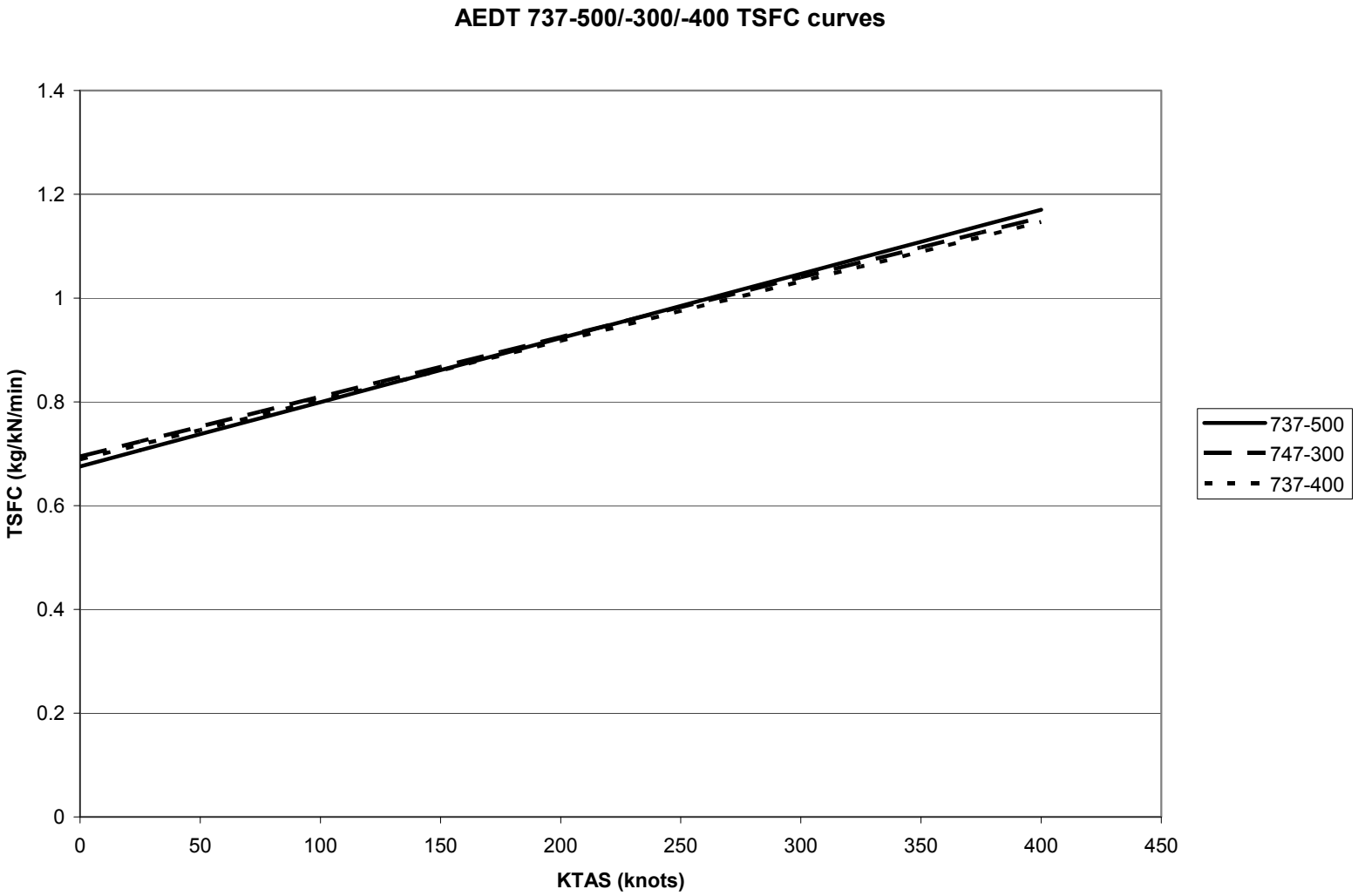
- Arrivals are modeled as fixed point profiles using the thrust from the FDR – we use the FDR thrust applied to the modeled TSFC to calculate fuel flow

The AEDT fuel burn model process (cont.)

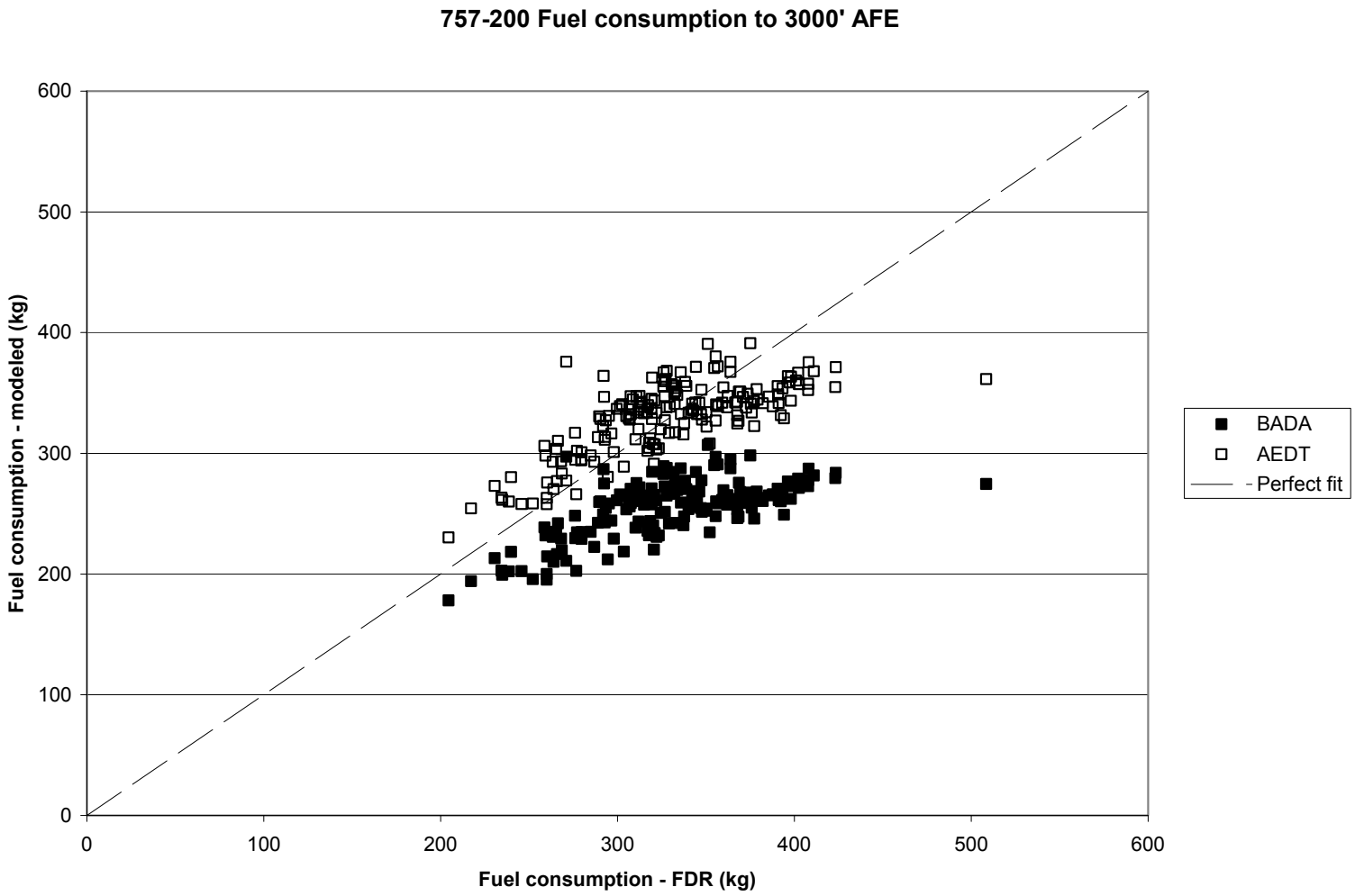
Using this process, we have generated fuel burn data for a number of Boeing aircraft:

717-200	747-400	MD-11
737-300	757-200	MD-81
737-400	757-300	MD-82
737-500	767-300	MD-83
737-700	777-200	
737-800	777-300	

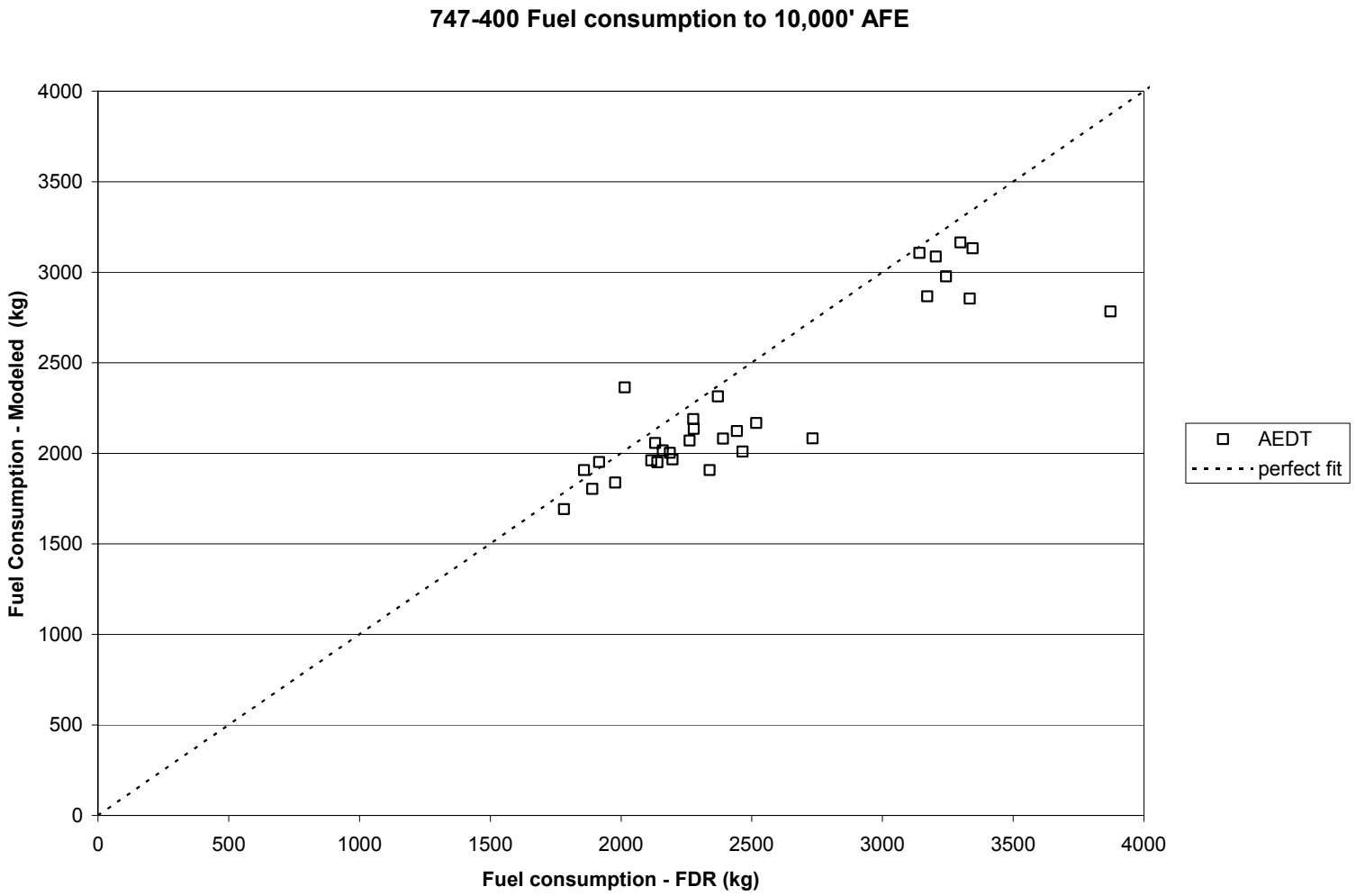
AEDT TSFC variation



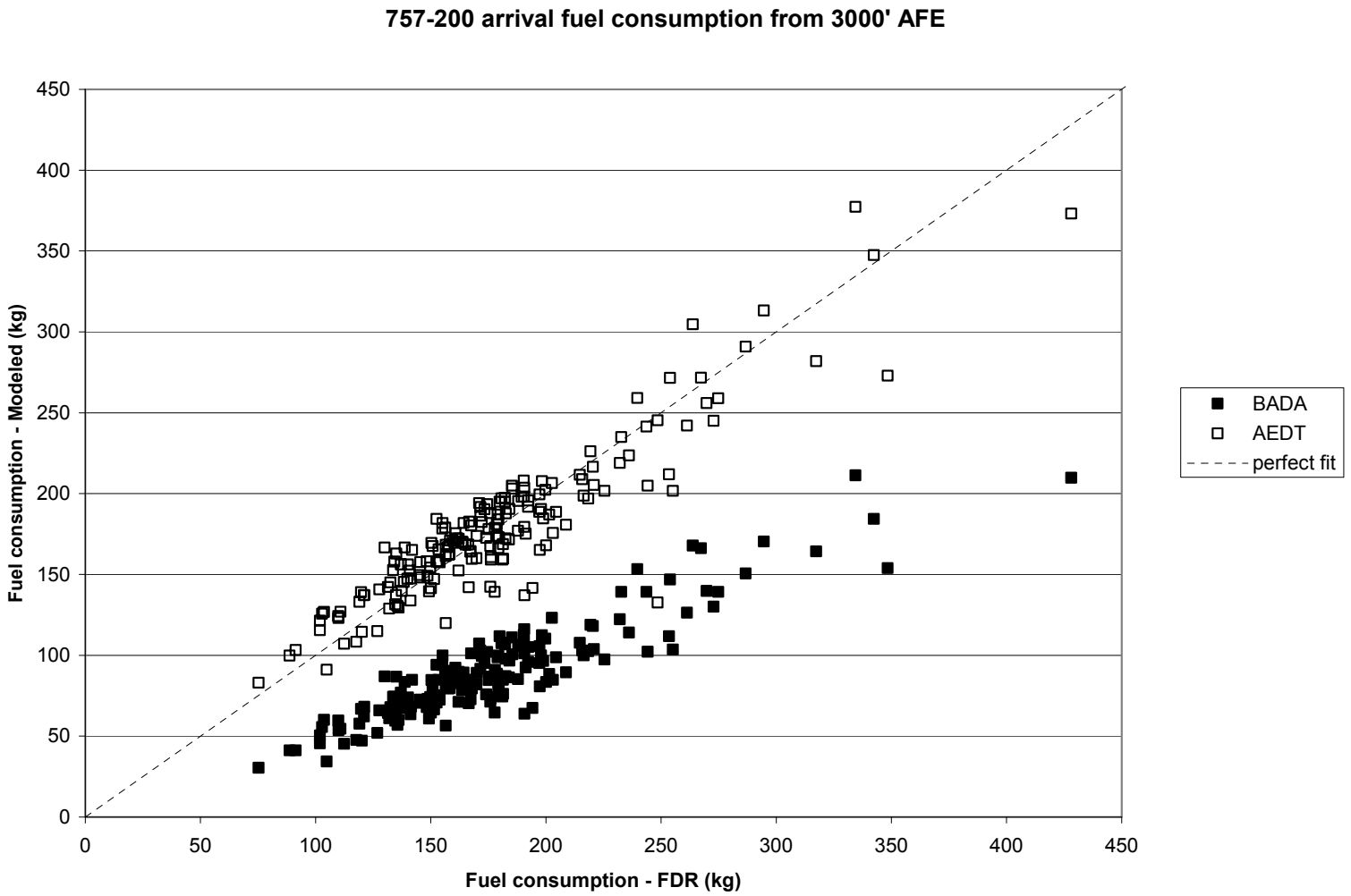
Modeling results – 757 departure



Modeling results – 747-400 departure



Modeling results – 757 arrival



Summary

- We have a process in place to generate airplane performance data which in turn can be processed to create TSFC methods in the FAA's environmental models
- These airplane performance tools-derived methods match the FDR data better than the existing BADA-based methods in the terminal area
- We have added the new fuel burn data for the current generation of Boeing airplanes into the AEDT database

Next steps

- Continue analyses of recently received U.S. carrier FDR data (expected completion: Dec. 08)
  - Goal: Determine impact of using standard arrival procedures in lieu of actual procedures
- Re-run existing CDA data at Miami after the new method is integrated with the AEDT radar track processing tools (expected completion: Jan. 09)
  - Goal: Determine impact of improved operations on fuel burn
- Acquire other manufacturers' aircraft performance tools (long term)
  - Goal: Improve terminal area fuel burn for all major in-production aircraft

Comments and Questions…

David A. Senzig
U.S. Department of Transportation
John A. Volpe National Transportation Systems Center
Environmental Measurement and Modeling Division, RTV-4F
55 Broadway
Cambridge, MA 02142
617.494.3348
david.senzig@dot.gov

Back-ups

Intermediate fuel burn models

Equation 1 (Original BADA):

$$TSFC = C_{f1}\left(1 + V_{TAS}/C_{f2}\right)$$

Equation 2 (Modified BADA w/BCOP):

$$TSFC = C_{f1}\left(1 + V_{TAS}/C_{f2}\right)$$

Equation 3 (Volpe TSFC):

$$TSFC = k_1 + k_2 V_{TAS} + k_3 h_{MSL} + k_4 F/\delta$$

Equation 4 (Yoder TSFC):

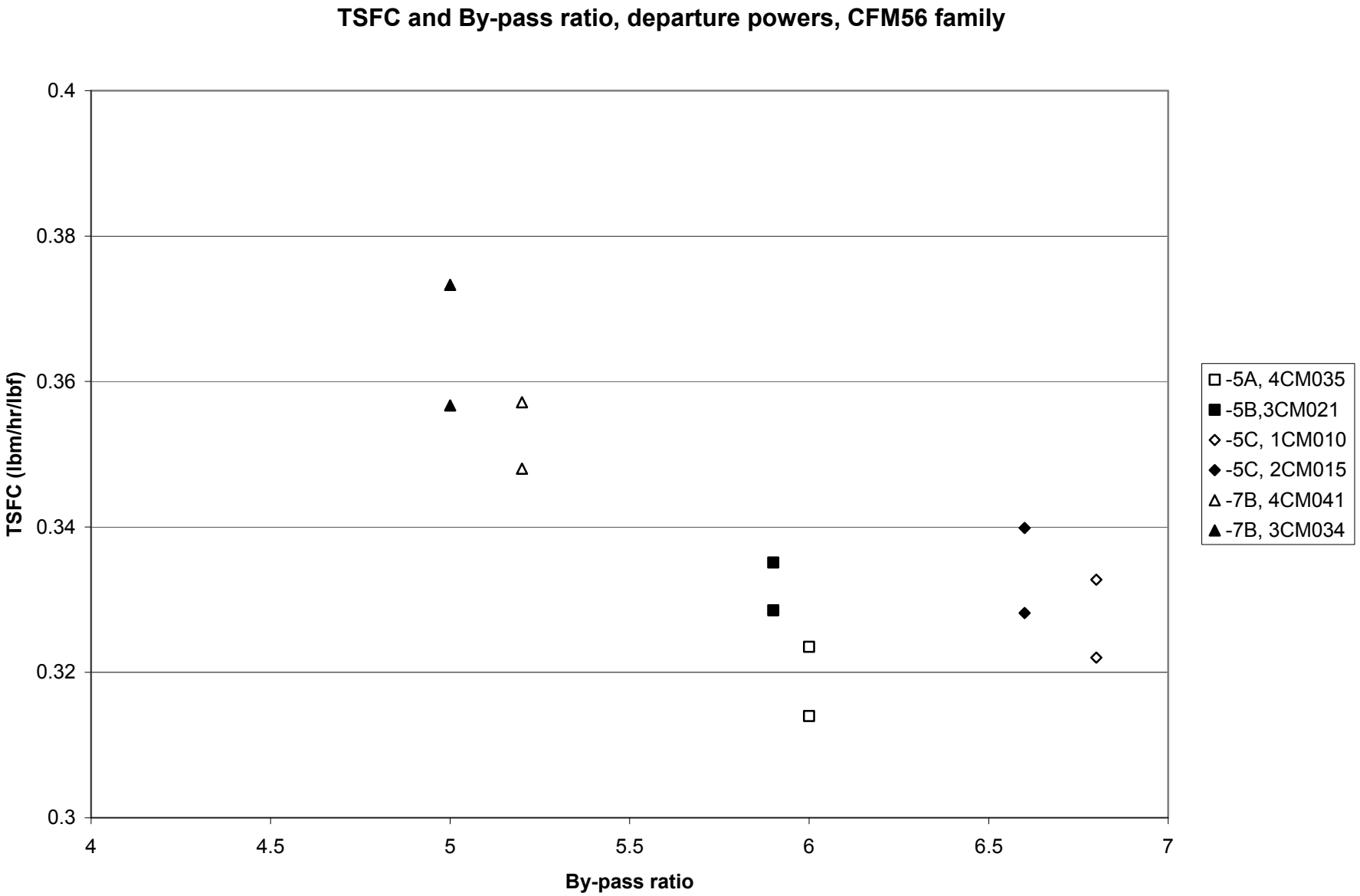
$$TSFC/\sqrt{\theta} = \left[\alpha + \beta_1 M + \beta_2 e^{-\beta_3\left(\frac{\tau}{\delta^{0.9}}\right)^{0.3}}\right]$$

Equation 5 (Modified Yoder TSFC):

$$TSFC/\sqrt{\theta} = \left[\alpha + \beta_1 M + \beta_2 e^{-\beta_3\left(\frac{F}{\delta}\right)^{\eta}}\right]$$

FDR v. BADA Fuel burn to 3000' AFE (average)

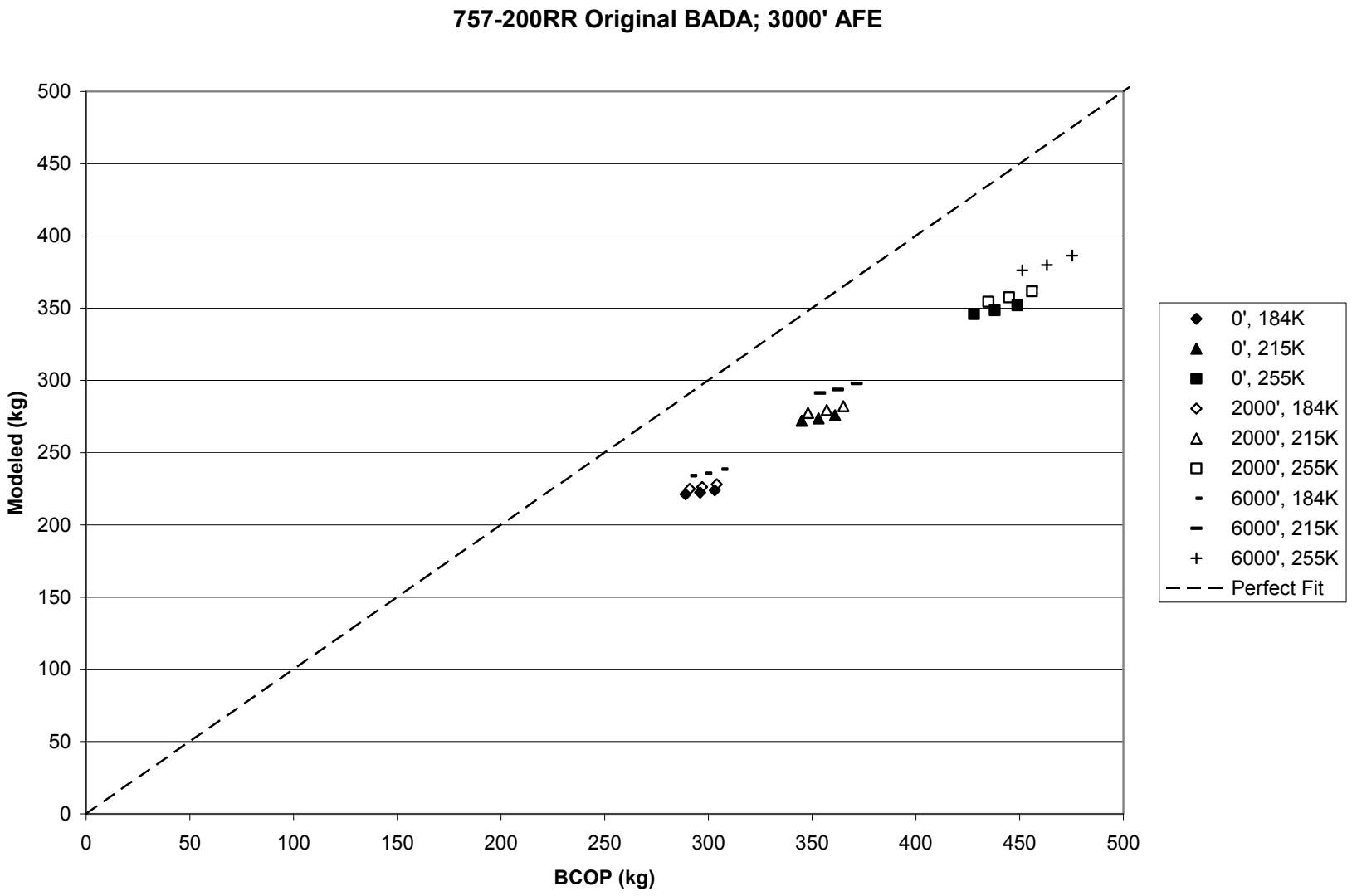
Aircraft	Measured (FDR)	Modeled (BADA)	Difference	Difference (%)
757-200	328 kg	262 kg	-66 kg	-20%
767-300ER	464	552	+88	+19%
777-300ER	736	1131	+395	+54%
A319	181	189	+8	+5%
A320	198	278	+80	+40%
A321	241	268	+27	+11%
A330-202	639	769	+130	+20%
A330-223	680	877	+196	+29%
A330-243	539	741	+202	+37%
A340-313	956	1104	+148	+16%
A340-541	1013	1258	+245	+24%
BAe-146	170	388	+218	+128%


TSFC and By-pass ratio, departure powers, CFM56 family
TSFC (lbm/hr/lbf)
0.4
0.38
0.36
0.34
0.32
0.3
4
4.5
5
5.5
6
6.5
7
By-pass ratio
-5A, 4CM035
-5B,3CM021
-5C, 1CM010
-5C, 2CM015
-7B, 4CM041
-7B, 3CM034

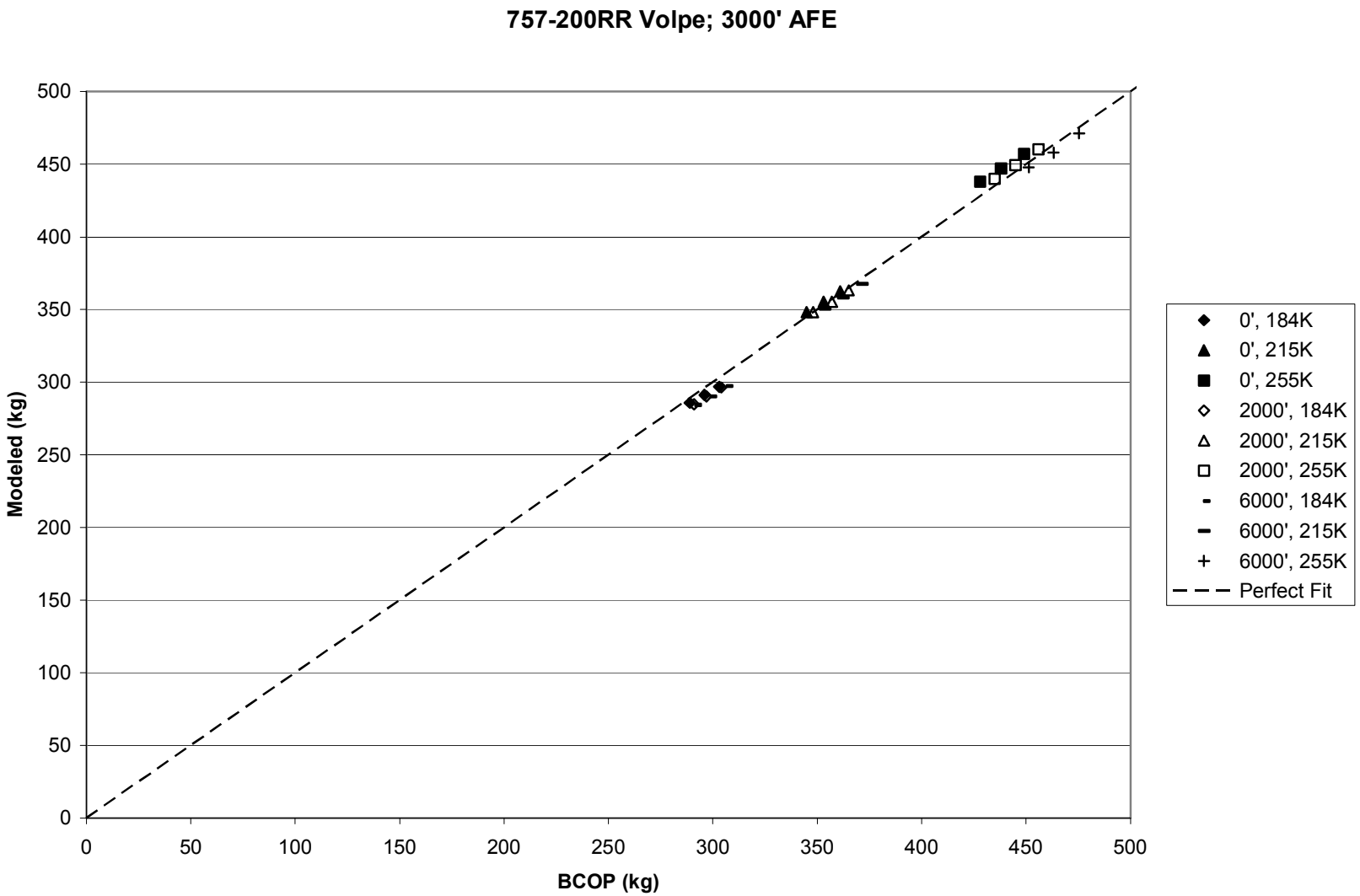
The proposed fuel burn models (details)

- Preliminaries: Sensitivity runs to determine parameters of interest
  - Multiple runs with different parameters held constant
  - Primary focus was 757-200/RB211-535 since we had a three-way match with FDR/AEDT/BCOP
- Determine which of seven proposed fuel burn methods would most closely mimic BCOP

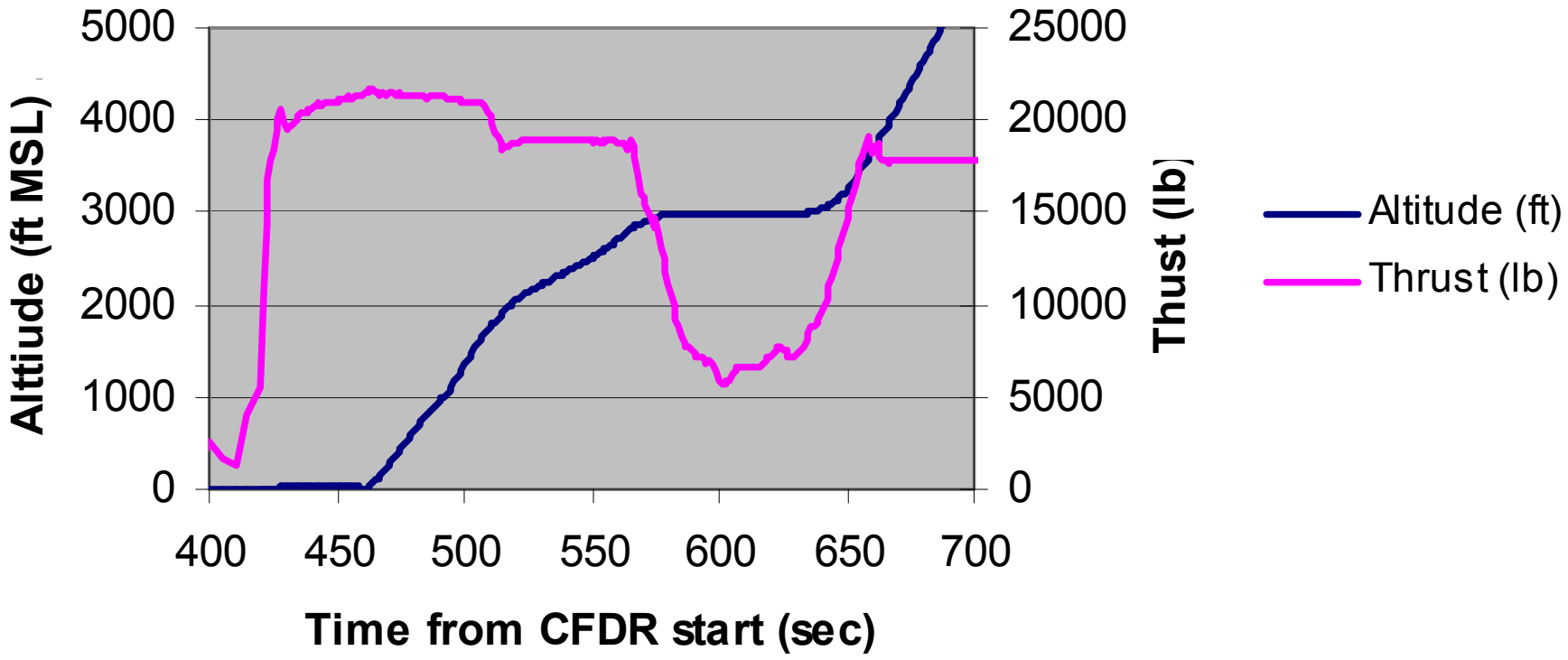
The proposed fuel burn models (details)



The proposed fuel burn models (details)



Flight 119033, example of ATC hold



757-200 Arrival TSFC